Integrated management strategy of pests in response to climate change - a case study of oriental fruit fly

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ABSTRACT

Based on the climate change and the fact that pests have been able to adapt to the island's climate and the environment of crops, their biological characteristics passed down by heredity continuously. These pests with their annual or seasonal peak of population fluctuation often resulted as epidemic pests year by year. The epidemic costs growers greatly in order to suppress pest damage. However, most pests will re-establish new population by dispersal, seeking refuge, or media transmission. If one cannot master the traces of pests, which often make effective prevention and control of material efficiency greatly discounted, so it is urgently needed to develop pest-monitoring technology in the field. With the progress of computer information technology, it can now effectively manage the big data from long-term collection. In order to show the pest dynamic information, it is ideal to use the geographic information systems (GIS) and other information networks. To establish the geographical distribution and density monitoring data in Taiwan, we set up 61 stations to collect and show the spatial dynamics of pest population and the risk of crop damage in 1994. In addition to collect the data of population density per ten-day, it provides a common control of fruit flies, masters the effective use of materials, and improves the prevention and cure efficiency. The purpose is to reduce the cost of crop production. Combined with the information of the complete geographic location, the distribution of pest spatial and land cover can be addressed quickly, and so as to assess the risk of pest occurrence and damage, which in turn improves the overall control efficiency. But the climate change has become a major global issue, researchers have started to predict the potential distributions of pest and the areas they cause economic crop damage based on the climatic data and biological models of development. Based on the potential geographical distribution of pest species, ecological niche model postulated the species that can occur in a particular area with the appropriate survival environment, climatic factors, distribution, and other biological factors. In recent years, a tool referred to as CLIMEX (CLIMatic

IndEX) which could integrate with the application of information management platform, including spatial data, geographic analysis, artificial intelligence applications, data mining, and the development degree-day of organism's model, was widely used. The tool is to detect or predict risk analysis of the potential distributions of the pests and vectors. A stable and excellent risk management model can be established based on this analysis. This study is to explore the climatic effect on the potential distribution of pests and compare the difference of present monitoring system in Taiwan. In order to assess the climate change impact on the distribution of pest or other possible risks of invasive pest. The research focuses on population growth of the Oriental fruit fly (*Bactrocera dorsalis* (Hendel)). Two objects are addressed: (1) Comparison of the impact of climate change on different locations, and (2) Climate stress effects on the geographic distribution of pests. The study attempts to effectively forecast the probability of dispersal of pests. Then, a real-time warning and control measures could take action according to probability of occurrence which will be useful for the farmers to manage pest dynamic.

Keywords: monitoring, geographic information systems, CLIMEX.

INTRODUCTION

With perennial high temperature and humidity in Taiwan Island, the weather impact on crop productions, often because of increased population to plant quality during cultivated period, thus affect the interests of farmers.

As climate change is a global issue, most researchers attempt to use the climate model and climatic data to analyze spatial statistics of geographic information systems (GIS), select the climatic zone of crops or the risk pointers of pests, with the GIS operations and modules, the location of crop suitability and pest risk, collected a large number of pests by GIS layer, and then find out the regularity of its distribution, through the operation of ecological niche model, can draw the potential distribution, and then convert this data into map, can show the potential distribution of pests, effectively predict the probability of spread distribution. And then provide real-time warning and prevention measures, to provide the cultivation and pest management for the farmers. Pest management must be integrated into the whole cultivation management system, and properly set up the monitoring and preventive measures, and to practice the best prevention and control efficacy, and timely take appropriate preventive measures to achieve a multiplier effect.

By using GIS management, in addition to monitor the pest density of the island along with the climate change, and to provide the relevant geographical risk location, it can set an effective time to prevent the outbreak of the pests to achieve the desired effect. Based on the climate of the island, the pests have been able to adapt to the climate change and to the environment of the crops, the biological characteristics of the pests pass on by heredity, continuously, so that these pests each year or season will appear the peak of population, resulting in the occurrence of pests, that caused the production workers the greatest loss. However, most of the pests will re-establish new population by dispersal, seeking refuge or media transmission. If we can handle the traces of pests, often make effective prevention and control of material efficiency greatly, so the pest monitoring work on a considerable proportion, focus on the epidemic situation can make effective use of materials. Through geographic information system technology and digital imaging technology, a pest risk distribution can be provided in detail and with the high risk of location of agricultural environment. With the information technology, the data can be effectively managed to their respective geographical location.

Integrated farmer association's personnel can set up monitoring network, such as for oriental fruit fly, that can regularly provide the farmers early and timely implementation of control measure. Rapidly handling on the spatial distribution and host plant location can be used to assess the risk of pest occurrence and damage, and to improve overall control effectiveness. In this paper, the implementation methods of density monitoring and the application in pest management are described separately.

I. Pest Monitoring System:

Pest management rarely relies on a single control practice, usually a variety of tactics are integrated to maintain pests at the economic threshold levels. The goal of the integrated pest management is not to eliminate all population. However, the aim is to reduce pest populations to less than damaging numbers. The control tactics were used by integrating varieties of pest control that include pest resistant or tolerant plants, and cultural, physical, mechanical, biological, and chemical control. Applying multiple control tactics minimizes the pests' population whether it will adapt to any one tactic dependent on the variety crops and economic cost in Taiwan.

A case study on monitoring of oriental fruit fly, the data collected at each time show the relative location, by inputting density data with the arrangement of colors

representing density variations. It can show the position and color difference of population size from the map. Displaying the color difference from the map, the density of the oriental fruit fly in Taiwan Island and that in neighboring areas can easily be identified. Pest density monitoring is an important work for pest control, because it is helpful to determine the timing of prevention and control of materials, to take appropriate preventive measures and to estimate economic loss. The monitoring system of the oriental fruit fly was established in Taiwan in 1994 (including Kinmen and Penghu). There are at least 61 townships (districts) of cultivated areas, each cultivated area is covered with nine traps by using GPS /GIS. The monitoring information was published as newsletters at the website (http://www.tari.gov.tw/form) on a 10-day interval. It is described as follow:

A. Set up the monitoring trap

(1). **How to choose monitoring site:** Choosing major cultivated fruit and vegetable areas or high risk densities areas, township as a unit, where several traps containing male lure agent were set.

(2). **How long should the time interval be set**: The time interval was determined based on the characteristics of pest life history, manually collected data in three minutes per month, regular implementation, and long-term cumulative data.

(3). **How to collect data information**: Collect the specimens by mail or fax quantitation data, geo-statistical analysis and drawing, display with geographic information system.

(4). **How to deliver the pest information**: Publish newsletter every 10 days as a reference for pest management, and send it by mail or e-mail to BAPHIQ (Bureau of Animal and Plant Health Inspection and Quarantine), Country government, and farmer association and, also the information will be placed on TARI web site (http://www.tari.gov.tw/) and the OPEN DATA Platform, in general, for free download or valuable applications.

B. Decision Making

Based on the long-term monitoring data, geographical location, host plant production, and marketing information, the implementation of fruit flies common prevention strategy can be summed up.

(1) Various kinds of control strategies should be implemented in each period, which can make the limited control materials more effective. The critical period of each phase varies slightly depending on the region, crop and climate.

(2) Geographical location and crop diversity: according to the color of the density, the climate change is used as the partition:

(3) In according to the historical data, the population distribution of fruit flies was higher than that of Changhua, Chayi, Tainan, Kaohsiung and Pingtung [(1)]. Based on nearly 20 years of monitoring data, it showed that the population distribution of fruit flies in high-risk areas. According to the climatic type potential geographical distribution and geographical location analysis, respectively, the different color grade risk presents the distribution as shown in Fig. 1.

(4) Through long-term monitoring of pest dynamics, its seasonal fluctuation is clearly illustrated. If combined with crop growth it can also make aware of the epidemic risk distribution area and with that the control measure can be fully implemented in the epidemic site.

This study analyzes the relationship between the situation in high-risk areas based on the cultivation area of fruit and the population data of fruit flies in the past years, and the evaluation of the pattern of the population dynamics for fruit flies. Through long-term collection of regionals population monitoring data, it can provide effective mastering of fruit fly dynamics in recent years, with the prevention of materials, and the acquisition of a strong preventive measures [(3)].

II. AW-IPM Case study in Taiwan:

The Area Wide-Integrated Pest Management (AW-IPM) control program of the oriental fruit fly (OFF, *Bactroceradorsalis* (Hendel)) was established in 2001 in Taiwan. All available OFF control techniques have been utilized (1) Methyl eugenol bait for male annihilation. (2) Protein bait for female fly control. (3) Bagging of the fruits. (4) Field sanitation. During recent years of the AW-IPM control practice, the OFF population decreased below the economic threshold and fruit production was still in excellent quality with a financial gain for the growers.

The area-wide (AW) control of the oriental fruit fly (*Bactroceradorsalis* (Hendel), OFF) was tested at Chiay in Taiwan. Successful control measure by practice area-wide control were obtained in large acreage districts, such as the 15,000 hectares sugar apple plantation in Chyai, as well as a single bitter gourd orchard with acreage less than one

hectare. Control methods were constructed for both districts and the technology has been transferred to local farmer associations for future implementation [3]. Growers in this area show a common interest in production, hence are highly cooperative in managing the fruit fly population. All available OFF control techniques have been utilized. The study mentioned a well organized OFF density monitoring program was established with some monitoring sites, which covered 500 ha cultivated area. So far, by promoting the AW-IPM control friendly environment that can be easily operated by the farmers. In general the OFF population were suppressed at a low density level within two years, and the population has been reduced to less than 2.0 FTD (fly/trap/day). However, the threat of invasion remains at outside areas. Therefore continuing suppression is necessary in Chung-Pu (Fig. 2). The small acreage model in guava is important since there are thousands of similar production areas like that in Chung-Pu, Taiwan, and field demonstration sessions on area-wide OFF control to other guava growers have been planned to start in the near future.

Another demo site in Fenglu. The control program had been started since 2012. We set up 18 monitoring sites to take an action to suppress the population densities to low density level based on the information collected. Through 6-year continuous controlling program, we achieved the outcome that led the population control to a limited area, especially the hot spot area in Fenglu (Fig. 3).

III. The climate change of CLIMEX

Climate change is one of the main factors affecting the geographical distribution and population of biological species. By estimating the geographical distribution and quantity of known species to estimate the climatic conditions required its occurrence, or by directly using biological data of species growth and development, adding climatic parameters and validating the predicted results with known distributions to adjust the climatic parameters of the selection. A stable and excellent risk management model can be established based on this analysis. This study is a basis to explore the climatic effect on the potential distribution of organisms and is compared with present surveys in Taiwan. In order to assess the climate change impact on the distribution of pest or other possible risks of invasive pest, this research focuses on population growth of the Oriental fruit fly. Two objects are addressed: (1) Comparison of climate change impact on different location. (2) Climate stress affects the geographic distribution of pests. To improve the accuracy of the system in predicting the potential geographical distribution

of the species. Based on the conceptual design of the CLIMEX [2, 4], the potential geographical distribution and relative abundance dynamics of the species are predicted by analyzing the climatic conditions in the areas where they have occurred. Early in Australia it was used to predict the potential geographical distribution of exotic plants and agricultural pests in order to manage such species. It has since been used all over the world to analyze the distribution of suitable living areas for agricultural diseases, weeds, and other arthropods.

The theoretical basis of the model of potential geographical distribution of species is based on the ecological niche model, which assumes that when a species appears in a region, the region must have suitable conditions for survival, such as climatic factors, crop distribution and other factors. The biological climate model for predicting species is based on two basic assumptions: (1) the species passes through 2 periods within one years, that is, a period suitable for population growth and unsuitable for survival. This implication is the biological species' birth and death phenomenon (2) climate is the main factor affecting species distribution, using a series of parameters to describe species' different responses to climate, stress index (Stress Indices, SI, cold, hot, dry and wet), as well as the relationship of factors to the survival of population in extreme climatic conditions.

The climatic parameters required to describe the species are mainly composed of three components: Growth index (GI), Stress index (SI), and other limiting conditions. The growth index includes the most appropriate temperature, humidity range and other suitable environment for growth and reproduction, and the adversity index includes climatic factors that limit the extreme temperature and humidity of species survival, including the parameters of other joint effects, such as diapause and effective accumulated temperature, based on these 3 parameters, The species Eco-climate index (EI) is used to synthesize the most appropriate climatic conditions and suitable habitats for species. The brief description is as follows:

1. **Growth index (growth index)**

The growth indices can be divided into weekly growth indices (weekly growth Index, GI_W) and annual growth indices according to the time scale (annual growth Index, GIa), the annual growth index is calculated on the basis of the weekly growth index, in which the growth indices of species are related to temperature, humidity

and illumination, taking into account the diapause of insects and the effects of plant (dormancy) on growth.

Diapause is an adaptive performance of species to extreme environments, low temperature or insufficient plant sunshine (such as winter diapause), or too long sunshine and too high temperature can induce diapause (such as summer diapause). Diapause index indicates the effect of diapause on the growth and development of species, and if the species were found as diapause, the diapause index DI_w=0; otherwise, the weekly Diapause index DI_w=1. In Taiwan, diapause is uncommon in agricultural pests.

2. **Stress Index (Stress index)**

There are 4 commonly used adversity indices: cold stress (CS), thermal stress index (Heat Stress, HS), wet stress index (Wet Stress, WS), dry stress index (Dry Stress, DS). It means that if any one of the indicators of adversity is greater than the extreme environment, the species cannot survive.

3. **Interaction (interaction) Stress index**:

Refers to the interaction between climatic factors, thermal - Wet stress index (Hot-wet Stress, HWS), thermal - Dry Stress index (hot-dry Stress, HDS), cold - Wet stress index (Cold-wet Stress, CWS), cold - Dry Adversity index (cold-dry Stress, CES). For example, the thermal - Wet stress index is used to indicate the effects of poor environment on the growth and development of species, the temperature range of species growing from the base development temperature (DV0)), the appropriate temperature lower threshold , the upper threshold to the highest development temperature (DV3). The humidity range from the minimum humidity (SM0) required for development to the highest growth humidity (SM3), exceeding these scope of adverse environmental conditions can lead to negative population growth (negative population growth).

The indices of Growth, Stress and interaction (interaction) were integrated into the eco-climatic Index, and the range of values 0~100, when the value is close to 0, it indicates that the species is unsuitable, and that the environmental conditions of the region are ideal. The smaller the EI value, the less suitable the region is for species to survive; the greater the EI value, the more suitable the region is for the species to

survive. Normally, when EI is greater than ten, species can survive, and EI is greater than 100, indicating that the area is ideal for species to survive.

In this study, the influence of climate change on the geographical distribution of important pests is studied, and the influence of climatic factors on the potential geographical distribution of pests in Taiwan region is CLIMEX by using the biological climate model, which is consistent with the existing survey geographic data. This can be used to assess the impact of climate on the distribution of such pests or the risk of other possible invasive pests. The Oriental Fruit fly is the target pest, making its potential geographical distribution in the world, exploring in Asia the production and comparison of the growth index and the biological climate index of oriental fruit flies, as illustrated in the following illustration:

A. **Climate change impacts on the potential distribution of pests in different regions and eras:** With yellow (EI<10) suitable for survival to red (EI>60) the most suitable for survival of the regional changes, from three years of climate change in the context of Asian and Southeast Asia in the Oriental fruit flies, the potential geographical distribution of the impact of a greater. It is not obvious to the Taiwan region that the insect is affected by the climate **(Fig. 4).**

B. **Restriction conditions on the geographical distribution of pests**: Extreme temperature or high rainfall will have a significant impact on the geographical distribution of the population. In addition to the central mountains, the probability of distribution is small, and the other oriental fruit flies are suitable for survival. Compared with the geographical distribution of the Oriental fruit flies, which were established in the field for a long time, the situation in the south-central region was almost suitable, and other areas could be adjusted or reinforced by other factors, even the difference in latitude was not obvious. According to potential geographical distribution of fruit flies evaluated by the biological climate model, and it was found that the western region and the east had a very suitable trend for the survival of fruit flies obviously illustrated in the blue and yellow areas.

C. **The EI value of geographical area is estimated by CLIMEX**: The climate is suitable for growth and development, and food available supply is abundant that leads to difficult control of pest damage and outbreaks are the most likely outcome. If the extreme climate affects the growth of crops that leads to poor food quality that

in turn make the agricultural pests need to overcome adverse climatic conditions resulted in an unstable population growth for the pests. In order to analyze the distribution of harmful bio-adaptive growth regions, if combined with the distribution data of host pant, while using various methods to interpret the data, it can be closer to real situation, which will be helpful to the early warning decision of the hot spot of the pest epidemic situation in the future. As climate factors influence crop growth, it also affects the growth of agricultural pests, and the relationship between pest and host crops, which has achieved the spread and control of agricultural pests.

D. **Climate spatial information integration**: a large amount of domestic climate data (Central Weather Bureau, https://www.cwb.gov.tw/) and downloaded global climate change scenario data (CLIMond, https://www.climond.org) are available. Due to the general geo-spatial interpolation mode (such as IDW, Kriging) often fails to fully reflect the effects of factors such as the terrain environment on climate, so it is necessary to grid the spatial data into the climate format developed by using PRISM model, interface with OPEN platform from the Central Weather Bureau. The content of the data provided the identification of the data set project and content, and released by XML data analysis of archives for the climatic data is spatially measured, and the daily real-time climatic data of the weather station in the whole Taiwan region are gridded spatial interpolation by using GIS to obtain the climatic grid data. After that, the data of pest grids site are interchangeable with interface properties, which can be combined with meteorological disaster protection early warning and land cover layer, as the relevant database of land use in Taiwan. Combined with platform is to estimate the degree day of the pest. The purpose is to explore the impact of climate change on pest or food security and risk assessment generation, the potential geographical distribution of pests in Taiwan was established by CLIMEX ecological niche model, which could be used as an assessment of potential geo-spatial distribution of invasive pests or natural enemies, and the basis for negotiation or policy of quarantine units had been provided.

Future prospects

A. According to the regular pest monitoring situation, the annual fluctuation data are provided regularly

(1) To assist in providing local pest outbreaks and distribution for the farmers' associations, township district offices and cooperative sites to. To give advice on the dynamic information and prevention of pest in the island, and to promote the epidemic and response in the event of production and marketing organization.

(2) To provide and activate fallow production area, carry on the notification mechanism of important pest epidemic information and the implementation of plough or pest management data.

(3) To establish the mapping database for the density and spatial distribution of important pests in the whole Taiwan, accumulated from long-term data has been built much more data of major pest density changes in the past years. Regional pest field monitoring data, which provides research subjects for long-term species ecological survey or species diversity. Pest density monitoring data, with the interface to provide complete land cover, climate disaster and pest risk assessment, to promote the protective operation for farmer.

(4) To arrange the best decision making and control calendar formulation. To finish the outcome, we must investigate the dynamics of pests in the field and analyze the growth and decline of different regions in different periods as a density index for the preventive measures. The means of the level of population can be taken as follow:

(a) It should be no need to take preventive (do nothing);

(b) It should be adopted by prevention and control strategy, according to the degree of prevention, suppression, and eradication.

(c) It should use chemical control: the formulation of rational use of pesticide strategy, the use of different types of pesticides with different mechanisms of the agent, to strengthen the effectiveness of prevention and resistance production.

(d) It should be done with control calendar dependent on the population fluctuation.

(e) It should practice the integrated pest management.

(f) It should implement the area-wide control (island-wide control).

CONCLUSION

Getting rapid information can help us to understand and solve many ecological problems such as insects. Due to the rapid development of network applications, the information system will be more intelligent on the network. In future, the system will have announces for growers to practice early pest management action. It will reduce pest outbreaks and the economics losses. Integration of the consultation information platform to connect pest diagnosis system including pest risk early warning query, pest generation change query, pest monitoring data query, climate data query, will be mainly to provide farmers, researchers. So they can quickly master the distribution of pest spatial and hosts, so as to assess the risk of pest occurrence and damage, and improve the overall control efficiency. Meanwhile the information transmission, the relevant units in time to grasp the latest outbreak to take effective means of prevention and treatment can be achieved. The system not only compares the implementing efficiency of each control area to promote the confidence of farmers, it can also objectively assess the fairness, efficiency and maneuverability of the distribution of materials.

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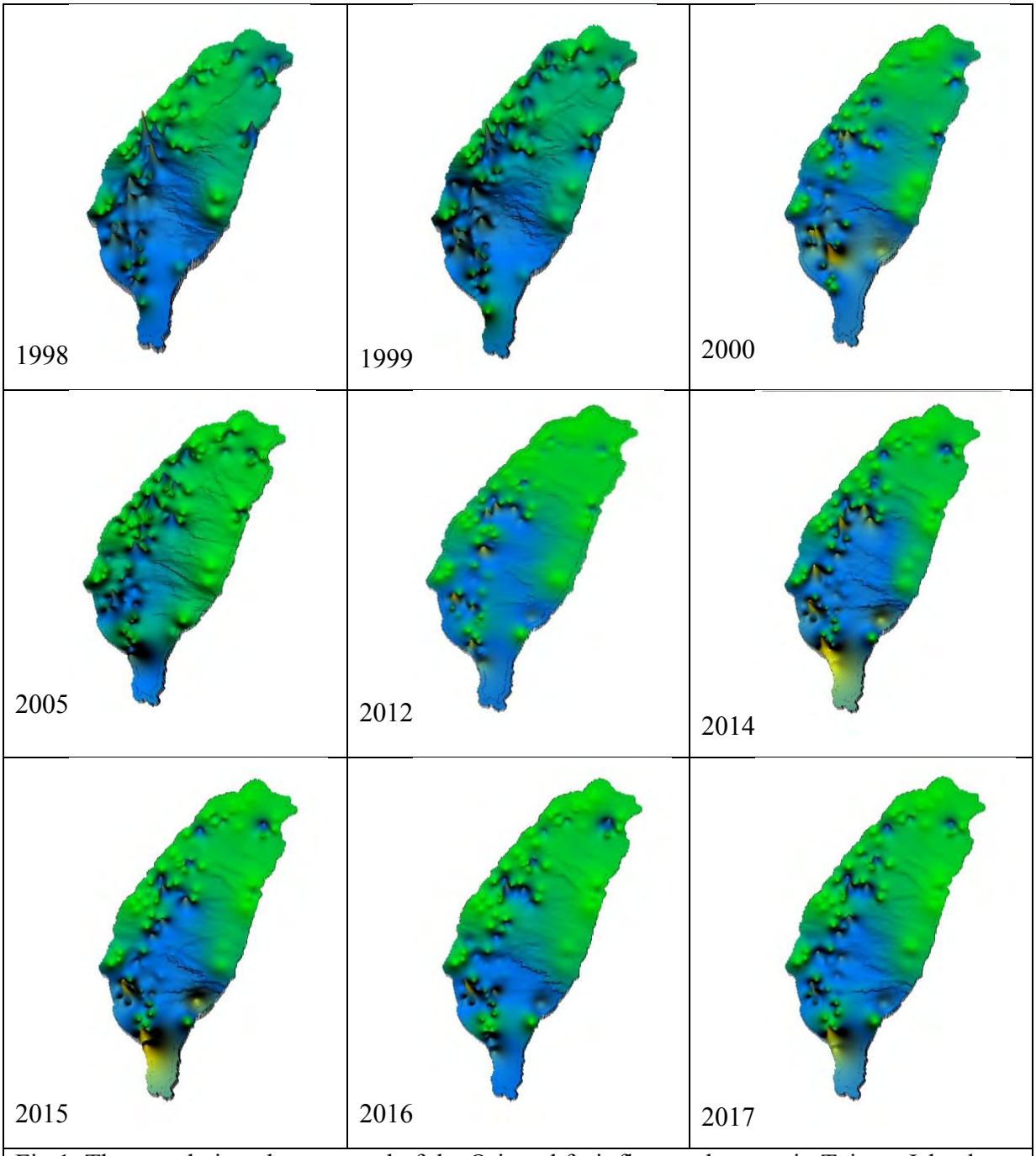

Fig.1. The population change trend of the Oriental fruit fly year by year in Taiwan Island.

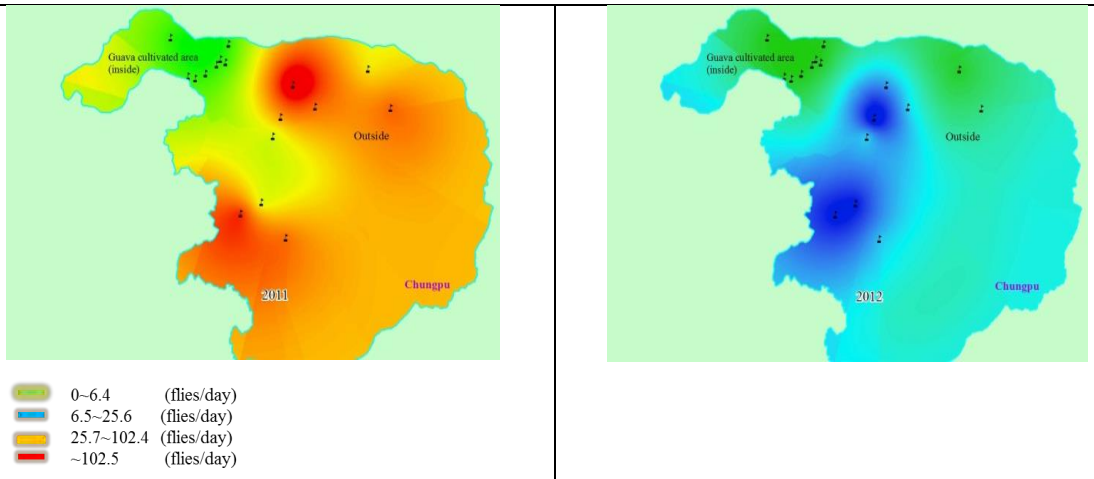

Fig. 2. The population change trend of the Oriental fruit fly at ChungPu from 2011 to 2012.

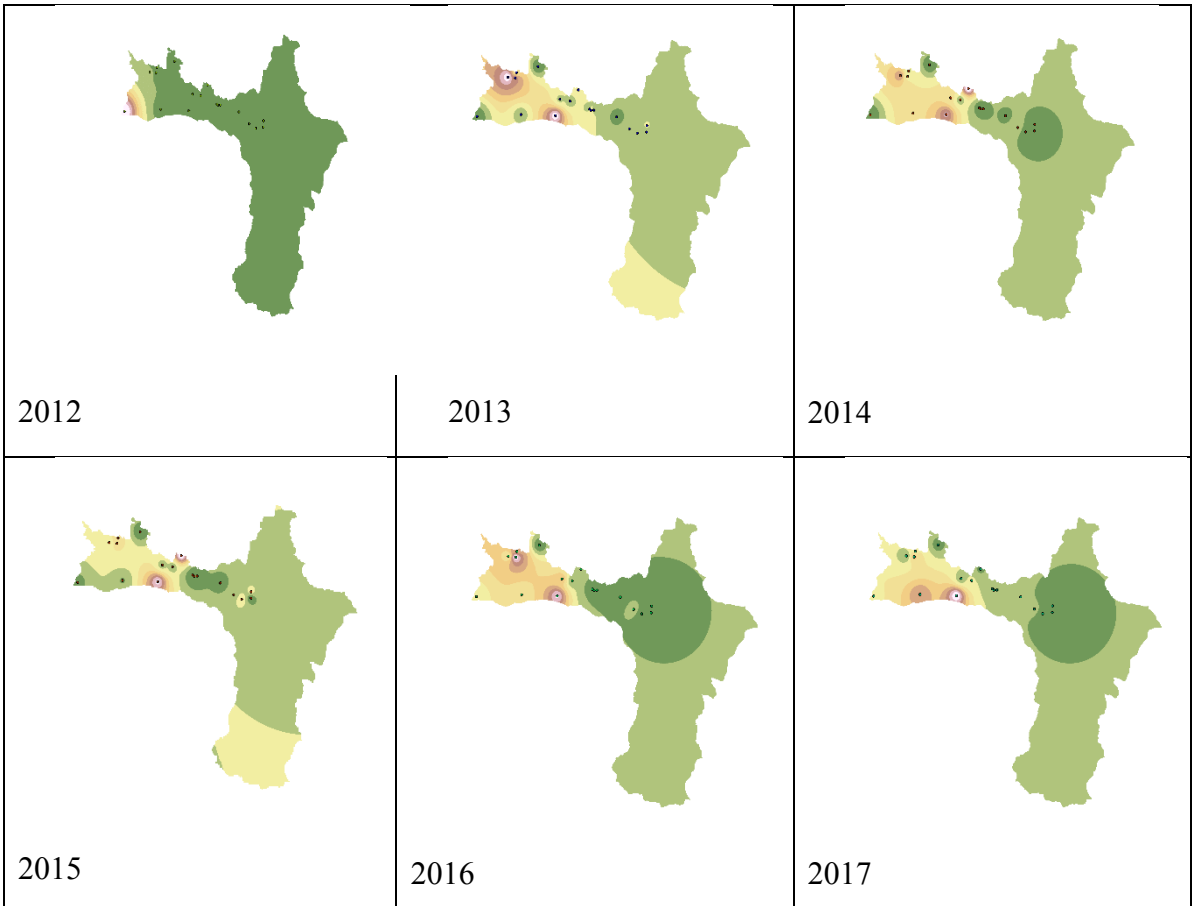

Fig 3. The population change trend of the Oriental fruit fly at FengLu from 2012 to 2017.

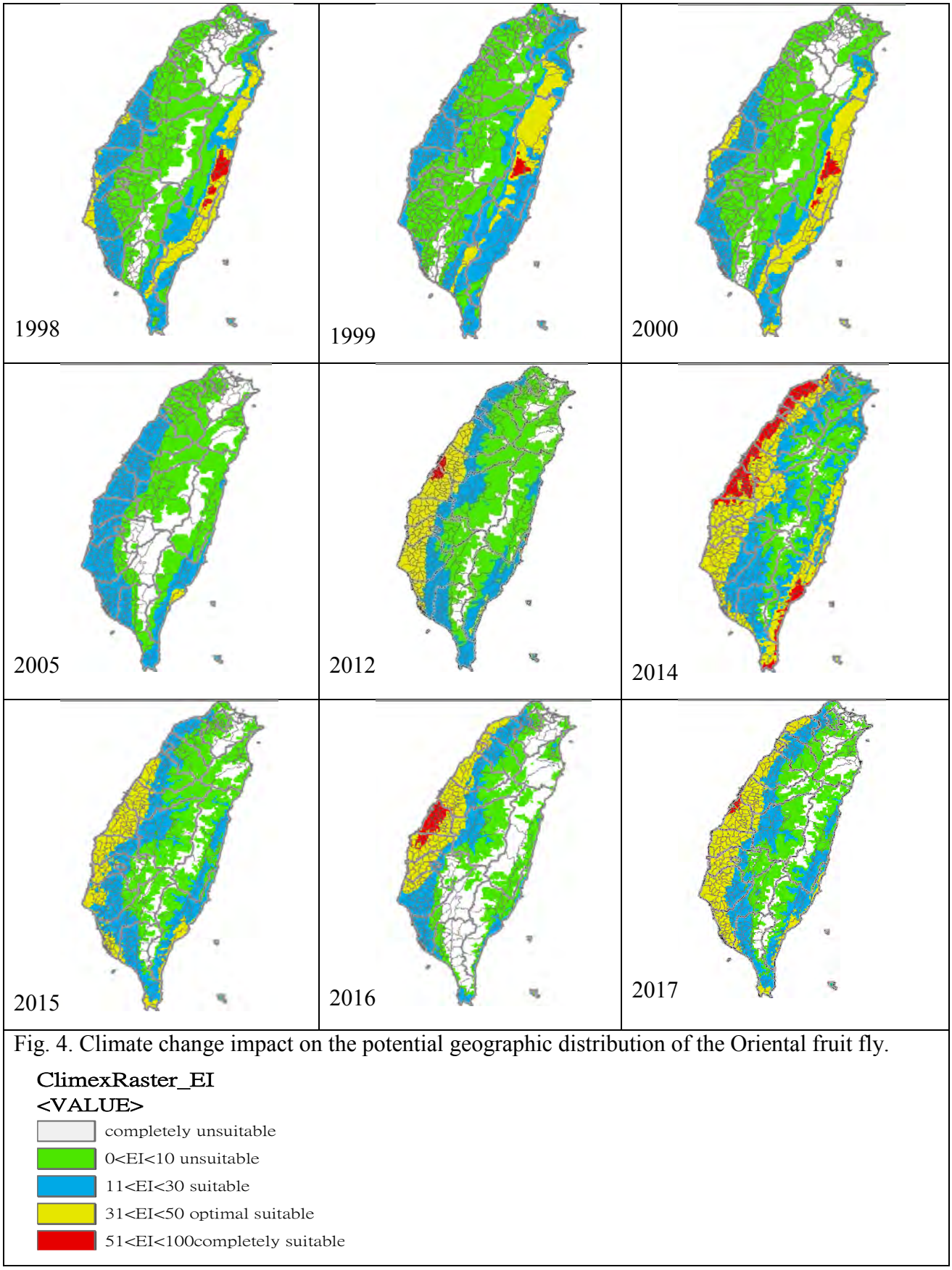

Fig. 4. Climate change impact on the potential geographic distribution of the Oriental fruit fly.